METHOD AND APPARATUS FOR FORCED CURRENT SHARING IN DIODE-CONNECTED REDUNDANT POWER SUPPLIES

FIELD OF THE INVENTION

[01] The present invention relates in general to power supply circuits, such as those employed in
5 telecommunication circuit applications, and is particularly directed to a feedback control mechanism for a diode-ORed, redundant power supply system, that effectively 'forces' the non-dominant power supply to continuously share a portion of the load current, and
10 thereby enables the non-dominant power supply to immediately respond to a load change, such as an interruption in the operation of the dominant power supply.

BACKGROUND OF THE INVENTION

15 [02] Designers of power supplies for electronic equipment currently face two significant problems: decreasing voltage requirements and redundancy. The first is due to the fact that, as electronic equipment has become more
20 complex, the industry has been steadily migrating to lower operating voltages in order to reduce power consumption.

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The second is based upon the need to make this complex equipment more robust than its predecessors. Robustness comes in the form of redundant systems, such as back-up power supplies.

[03] More particularly, back-up power supplies must be designed so that, in the event of a primary supply failure, the back-up or auxiliary power supply will immediately take over without causing an interruption in operation of the circuit being powered. This is especially true in the communications industry, whose products, such as subscriber line interface circuits or 'SLIC's, are required to conform with a very demanding performance specification, including accuracy, insensitivity to common mode signals, linearity, low noise, filtering, ease of impedance matching programmability, and low power consumption.

[04] Moreover, as designers of integrated circuits employed for digital communications, such as codecs and the like, continue to 'lower the voltage supply rail bar' requirements for their devices (e.g., from five volts down to three volts and below), not only is the communication service provider faced with the problem that such low voltage restrictions may not provide sufficient voltage headroom to provide a low impedance-interface with its existing SLICs (which may be designed to operate at a VCC supply rail of five volts), but the power supply employed must conform with very exacting requirements.

[05] The trend of decreasing output voltages has thus increased the design difficulty. A five volt power supply

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that is required to maintain a five volt output within a five percent tolerance means that it can swing 250 mV in either direction and still 'meet spec'. In contrast, a two volt power supply that is required to maintain the same five percent tolerance is allowed to vary only 100 mV in either direction. Obviously, this problem becomes exacerbated as circumstances call for even tighter tolerances and lower voltages.

[06]   In the case of redundant power supplies, two or more power supplies are connected in parallel, for example, by means of a relatively common technique called diode-ORing, diagrammatically illustrated in Figure 1, so that if one power supply fails, the other supply will take up the load without causing system shutdown. To this end, the redundant supply of Figure 1 has a first power supply (P.S.) 1, that produces an output voltage V1, while a second power supply 2 produces an output voltage V2. The two power supplies are connected to an output bus 3 through associated ORing-diodes 4 and 5, respectively, through which currents I_1 and I_2 flow to a node 6 - the point from which an output voltage V3 to a load is supplied.

[07]   Typically, the output voltage will vary somewhat from supply to supply, with component tolerances, so that in a redundant arrangement such as shown in Figure 1, that power supply having the higher reference voltage V_{REF} will supply most of the load current I_L. Since the voltage drop across a diode is directly proportional to the current flowing through it, then whichever power supply is

sourcing the most current will produce the larger diode drop. On the other hand, the power supply having the lower reference voltage will have a lower output voltage, and supply less current, producing a lower diode voltage drop.

5 With the two power supplies diode-ORed together, equilibrium is quickly reached and each power supply provides some percentage of the current - provided that the voltage reference differential between the two supplies can be accommodated by the diode voltage drop.

10 **[08]** A power supply's output voltage should not have a large dependence on its output current load. However in the diode-ORing case, the output voltage V3 is dependent on the load or output current I_L. In addition, since the voltage drop across the ORing-diode is also dependent on

15 the output current, the output voltage V3 can be hard to predict and regulate. To accommodate this problem, power supplies generally employ some form of closed-loop control that senses the output voltage. This information is fed back to the power supply's controller and compared to an

20 internal voltage reference, so that the controller may regulate the supply's output voltage at a constant voltage under different conditions.

[09] In the power supply architecture of Figure 1, voltage feedback (F.B.) is supplied to reference inputs REF 1, REF

25 2 from the upstream (V1 and V2) sides of the ORing-diodes 4 and 5, so that the power supplys' controllers have no information about diode voltage drops. As a result, the output node voltage V3 is subject to the unpredictable voltage drops across the diodes. It is preferred to feed

back the voltage from the downstream or V3 side of the ORing-diodes, as shown in Figure 2, since this is the actual voltage that is being supplied to the load. With the voltage feedback point at the V3 side of the

5   ORing-diodes, the voltage drops across the diodes are no longer a problem, and the power supply with the larger reference voltage will establish the output voltage V3.

[10]   On the other hand, the power supply with the lesser reference voltage will turn off, since its feedback

10   exceeds its reference, so that all of the voltage to the load is sourced from the power supply having the higher reference voltage. Therefore, if the active (higher reference voltage) power supply fails suddenly, the inactive supply will be unable to start up immediately,

15   resulting in an interruption in supply voltage to the output node, and likely disruption in the operation of downstream electronic circuitry.

SUMMARY OF THE INVENTION

20   [11]   In accordance with the present invention, shortcomings of conventional diode-ORed, redundant power supply systems, such as those described above, are effectively obviated by a new and improved feedback control mechanism that forces the non-dominant or 'back-

25   up' power supply to share a (relatively small) portion of the load, which is effective to eliminate the shut off problem when regulating from the load side of the ORing diodes. The regulation control mechanism employed by the invention involves two functional components. The first is

to allow regulation on the common output bus of both power supplies. By regulating the voltage on the common output bus, the tolerance error added by the ORing diode is eliminated. The second is to force the non-dominant power

5   supply to share a portion of the load current.

[12] For this purpose, a voltage monitor circuit is coupled across each output-ORing diode. Each monitor circuit measures the voltage drop (V_d) across its associated diode and compares the measured voltage to a

10   prescribed minimum or threshold value. The result of the comparison is then fed back via a summing circuit to the control port of the power supply. If the diode voltage drop V_d as measured by a respective monitor circuit is larger than the minimum value, it is inferred that its

15   power supply is supplying an acceptable portion of the load current to the output node, and the monitor circuit produces a first output value (e.g., a logical high) at its output port.

[13] In response to this output from the monitor circuit,

20   the power supply controller continues to regulate the supply's output voltage at its present value and the monitor circuit is dormant. However, if the value of the monitored diode voltage V_d drops below its preset minimum value, it is inferred that the other power supply is

25   supplying the entirety of the load current. This causes the output of the monitor circuit to change state, which causes the power supply's controller to increase the output voltage and forward bias the monitored diode. This effectively 'forces' the non-dominant power supply to

share a portion of the load current, and thereby continuously maintains the non-dominant power supply in a ready-to-go state, so that it can immediately respond to a load change. The monitor circuit also compares the power
5   supply voltage with a further reference voltage, to insure that the power supply output voltage will not rise above a desired maximum.

BRIEF DESCRIPTION OF THE DRAWINGS

10   [14]   Figure 1 diagrammatically illustrates a conventional diode-ORed redundant power supply arrangement, in which voltage feedback takes place from the upstream sides of the ORing-diodes;

[15]   Figure 2 diagrammatically illustrates a conventional
15   diode-ORed redundant power supply arrangement, in which voltage feedback takes place from the downstream sides of the ORing-diodes;

[16]   Figure 3 diagrammatically illustrates the forced current-sharing, redundant diode-connected power supply
20   architecture of the present invention; and

[17]   Figure 4 shows the configuration of a respective monitor circuit of the forced current-sharing, redundant diode-connected power supply architecture of Figure 3.

DETAILED DESCRIPTION

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[18]   Before detailing the forced current-sharing, diode-connected redundant power supply architecture of the present invention, it should be observed that the invention resides primarily in a prescribed arrangement of

conventional power supply circuit components and regulation circuitry therefor, that controls the operations of such components. Consequently, the configuration of such components and the manner in which

5   they may be interfaced with power circuits, such as telecommunication equipment, have, for the most part, been shown in the drawings by readily understandable block diagrams, which depict only those specific details that are pertinent to the present invention, so as not to

10   obscure the disclosure with details which will be readily apparent to those skilled in the art having the benefit of the description herein. Thus, the block diagrams of the Figures are primarily intended to show the major components of the invention in convenient functional

15   groupings, so that the invention may be more readily understood.

[19] Attention is now directed to Figure 3, wherein a non-limiting, but preferred embodiment of the forced current-sharing, redundant diode-connected power supply

20   architecture of the present invention is diagrammatically illustrated as comprising a first power supply 10 having an output port 11 producing an output voltage V1, and a second power supply 20 having an output port 21 that produces an output voltage V2. As in the designs of

25   Figures 1 and 2, the supply 10 is connected to a common node 31 of an output bus 30 through a first ORing-diode 12, while power supply 20 is connected to output bus node 31 through a second ORing-diode 22.

[20] In accordance with the invention, a first voltage

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monitor circuit 14 is coupled across diode 12, while a second voltage monitor circuit 24 is coupled across diode 22. Each monitor circuit (to be described in detail with reference to Figure 4) is operative to measure the voltage

5   drop (V_d) across its associated ORing-diode and then compare the measured voltage to a prescribed minimum value. The result of the comparison is then fed back via a summing circuit to the control port of the power supply. For this purpose, monitor circuit 14 has its comparison

10   output 15 coupled to a summing circuit 16, which is also coupled to the common node 31. The output of the summing circuit 16 is coupled to control port 17 of power supply 10. Similarly, monitor circuit 24 has its comparison output 25 coupled to a summing circuit which is also

15   coupled to the common node 31. The output of the summing circuit 26 is coupled to control port 27 of power supply 20.

[21] If the diode voltage drop V_d as measured by a respective monitor circuit is larger than the minimum

20   value, it is inferred that its power supply is supplying an acceptable portion of the load current to the output node 31, and the monitor circuit produces a first output value (e.g., a logical high) at its output port. In response to seeing this output from the monitor circuit,

25   the power supply controller continues to regulate the supply's output voltage at its present value and the monitor circuit is dormant. However, if the value of the monitored diode voltage V_d drops below its preset minimum value, it is inferred that the other power supply is

supplying the entirety of the load current. This causes the output of the monitor circuit to change state (e.g., goes low), which forces the power supply's controller to increase the output voltage and forward bias the monitored

5   diode. This effectively 'forces' the non-dominant power supply to share a portion of the load current, and thereby continuously maintains the non-dominant power supply in a ready-to-go state, so that it can immediately respond to a load change.

10   **[22]** Figure 4 shows the configuration of each of the monitor circuits 14 and 24. For purposes of simplifying the present description, only monitor circuit 14 will be detailed, it being understood that the present description applies equally to the monitor circuit 24 of Figure 3. In

15   order to measure the voltage drop V_d across diode 12 a first operational amplifier 40 has its non-inverting (+) input 41 coupled via a voltage divider 46 (referenced to ground) to monitor the voltage Va at the upstream (anode) side of ORing diode 12, and its inverting (-) input 42

20   coupled via a resistor 47 to monitor the voltage Vb at the downstream (cathode) side of ORing diode 12. A feedback resistor 48 is coupled between the output 43 and inverting input 42 of operational amplifier 40.

[23] The output 43 of operational amplifier 40 is coupled

25   through a summing resistor 44 to the non-inverting (+) input 51 of a second operational amplifier 50 configured as a threshold detector. For this purpose, operational amplifier 50 has its inverting (-) input 52 coupled to a reference voltage 54. An integrating capacitor 55 is

coupled between the output 53 and inverting input 52 of the amplifier 50, and serves to provide a smooth transition between a change in the output state of threshold detector 50. The output 53 of threshold detector 50 is coupled through a diode 60 to a summing circuit node 61, which is also coupled through a resistor 62 to output node 31.

[24] The monitor circuit further includes a second threshold detector having its non-inverting input 71 coupled to the power supply output 11, and its inverting (-) input 72 coupled to receive a reference voltage 74. The output 73 of threshold detector 70 is coupled through a summing resistor 75 to the non-inverting (+) input 51 of threshold detector 50. As will be described, this additional threshold detector is used to insure that the output voltage will not rise above a desired maximum output voltage.

[25] In operation, the voltage drop V_d = Va-Vb across diode 12 is amplified by amplifier 40 and compared in threshold detector 50 to a reference voltage 54. If the output voltage of amplifier 40 A is above the reference voltage 54 then the output of the threshold detector 50 will have a first state (e.g., high), so that diode 60 will be back-biased and the monitor circuit will have no interaction with the operation of the power supply controller, as its monitors the output voltage applied to node 31. However, if the voltage at the output 43 of amplifier 40 drops below the reference voltage 54, the output of threshold detector 50 will have a second state

(e.g., low), so as to forward bias diode 60, and cause a reduction in the voltage being fed back to the power supply controller.

[26] As pointed out above, this reduction of the
5   controller feedback voltage effectively 'forces' the power supply's controller to increase the output voltage sufficiently to maintain current flow in the ORing-diode 12, and thereby keep the non-dominant power supply in a 'slightly' on or 'forced current-sharing' condition, that
10   enables it to immediately respond to a load change, such as an interruption in the operation of the dominant power supply.

[27] The threshold detector 70 compares the power supply output voltage Va with the reference voltage 74. As long
15   as the power supply output voltage Va is not higher than the reference voltage 74, the output of threshold detector 70 is low, the 'forced current-sharing' operation of the monitor circuit proceeds as described above. However, if the power supply output voltage Va exceeds the reference
20   voltage 74, the output of threshold detector 70 goes high. This forces the output of threshold detector 50 high, so as to return control of the power supply to the controller, to regulate the power supply's output voltage based solely on the controller reference voltage 54.

25   [28] As will be appreciated from the foregoing description, shortcomings of conventional diode-ORed, redundant power supply systems, enumerated above, are effectively obviated by the current-sharing feedback control mechanism of the present invention that forces the

non-dominant power supply to share a portion of the load current, so that it can immediately respond to a load change, such as an interruption in the operation of the dominant power supply.

5 **[29]** While we have shown and described an embodiment in accordance with the present invention, it is to be understood that the same is not limited thereto but is susceptible to numerous changes and modifications as known to a person skilled in the art, and we therefore do not

10 wish to be limited to the details shown and described herein, but intend to cover all such changes and modifications as are obvious to one of ordinary skill in the art.